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These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME I

(November 1972 - March 1973)

by

University of Guelph
Guelph, Ontario

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

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ABSTRACT

This study was designed as the first part of a three to five year project to determine the rates at which chemically treated sewage sludges may be safely applied to agricultural land.

Initial experiments with sludges resulting from sewage treated with lime, aluminum sulphate and ferric chloride are described in this report. The sludges were applied to three different soils at rates based on the total nitrogen content of each sludge.

The following aspects of sludge application to soil were investigated: rate of nitrogen transformation to soluble forms when chemical sludges were incorporated into sand-soil mixtures; bacterial contamination of runoff and groundwater; the macromorphology, micromorphology, and the chemical and physical states of the soil prior to application; the effect of sludges on plant growth; and, nutrient and heavy metal uptake by plants.

RÉSUMÉ

La présente étude constitue la première partie d'un projet de trois à cinq ans visant à déterminer la fréquence avec laquelle on peut sans inconvénient répandre sur des terres agricoles des boues provenant d'eaux usées traitées au moyen de produits chimiques.

On décrit les expériences initiales faites avec des boues provenant d'eaux usées traitées à la chaux, au sulfate d'aluminium et au chlorure ferrique. Les boues ont été étendues sur trois sortes de sols, avec une fréquence fixée d'après la teneur en azote de chacune des boues.

On a étudié les aspects suivants: vitesse de transformation de l'azote en composés solubles quand les boues provenant du traitement chimique étaient incorporées à des mélanges de sable et de terre; contamination bactérienne de l'eau de ruissellement et de l'eau souterraine; la macromorphologie, la micromorphologie et les conditions chimiques et physiques des sols avant l'épandage; l'action des boues sur la croissance des plantes; et la consommation en éléments nutritifs et en métaux lourds par les plantes.

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1. INTRODUCTION

Sewage and sewage sludge have been applied to agricultural land for many years (Law and Kerr, 1968; Rafter and Baker, 1894). Until recently, however, there has been little concern about resulting pollution of water with nutrients, heavy metals and other pollutants as a result of leaching from or erosion of the sludge deposits.

Sewage plants in Ontario with capacities exceeding one million gallons per day, located in the Lake Erie drainage basin, must by law have phosphorus removal programs operating by December 31, 1973. It appears that the chemicals most commonly used for phosphorus removal will be calcium oxide or hydroxide, aluminum sulphate, and ferric chloride. There is little, if any, information published on land application of sludges resulting from treatment with these chemicals.

This project was designed as the first part of a three to five year study to determine the rates at which sludge from lime, aluminum sulphate and ferric chloride treated sewage may be safely applied to agricultural land. Several different experiments were involved. Field experiments were planned for 1973 with both corn and grass as crops, using the three chemically treated sludges on three different soils. Although no sludge was applied during this study period, appreciable preparation and installation of facilities for these experiments occurred. A runoff study was initiated on two different slopes with two rates of application of one sludge. A greenhouse study is also in progress using three rates of the three sludges on two soils limed to different pH levels.

Rates of the three sludges applied in field and greenhouse were based on the nitrogen content. Sludge rates are therefore expressed in pounds of nitrogen per acre (kg/ha). These trials are discussed in more detail in the following report.

1.1 General Objectives

The objective of this project was to determine the maximum rates at which sludges resulting from chemical treatment for phosphorus removal can be applied to agricultural lands without polluting ground and surface waters with elements or organisms pathogenic to humans and animals, or reducing the quality or quantity of the crops produced. These rates are expressed in terms of pounds of nitrogen per acre.

2. FIELD RATE AND SOURCE EXPERIMENTS

2.1 Objectives

The objectives of the field rate and source experiments were: (1) to determine the application rates for the three chemically treated sludges which may be safely used on typical Ontario soils without adversely affecting crop yield, or nitrate and heavy metal content; (2) to determine the rates of sewage sludge application which may be used without contaminating groundwater with nitrates, phosphates and heavy metals; (3) to measure bacterial contamination of runoff and groundwater resulting from sludge application.

2.2 Materials and Methods

Sites were selected for the field study and, in the Fall, preparation was made for Spring application of sludges. To store and mix sludges for these experiments three concrete silos were built ranging in capacity from 2600 to 3600 cubic feet. The experimental sites were on a Conestoga loam soil at the Elora Research Station, a Lisbon sandy loam at the Hespeler (Cambridge) Research Station, and an Oneida clay or clay loam on a farm near Milton, Ontario.

The preparations were for trials at Elora, Hespeler (Cambridge) and Milton where corn was to be planted in 1973. Lime, aluminum sulphate, and ferric chloride treated sludges are to be applied at 178 lb N/acre (200 kg N/ha), 357 lb N/acre (400 kg N/ha), 714 lb N/acre (800 kg N/ha), and 1427 lb N/ha (1600 kg N/ha) rates each Spring starting in 1973 and worked into the soil before planting corn.

A grass trial was laid out at the Elora Research Station. The three chemically treated sludges are to be applied in Spring, Summer and Fall each year starting in 1973. The amounts applied are to be equivalent to the rates proposed for the corn trials.

2.3 Results and Conclusions

Although considerable effort and expense were involved in this phase of the contract no results will be available until late in 1973.

3. NITROGEN

3.1 Objectives

The objective of this preliminary study was to determine the rate of transformation of nitrogen in chemically treated sewage sludges to soluble forms when incorporated into a soil-sand mixture.

3.2 Materials and Methods

An analysis of the release of soluble nitrogen from soil treated with different chemically treated sludges was carried out in the laboratory.

Al-, Fe-, and Ca- treated sludges (equivalent to 12,000 μg N) were mixed with 30 g of a soil-sand mixture (1:1) and placed in a Buchner funnel. Treatments also included a check (no N added) and $(NH_4)_2SO_4$ addition. These treatments were incubated with the soil-sand mixture at about 0.1 bar moisture tension. They were leached periodically over a seven-week period and NO_3^- and NH_4^+ were measured in the leachates.

3.3 Results and Conclusions

A preliminary evaluation of the data showed that Fe- and Ca- treated sludges apparently do not inhibit nitrogen transformation in soil, whereas the Al- treated sludge did. The rate of appearance of nitrate-nitrogen was greatest for the Fe- treated sludge. The results suggest that the rate of N transformation in the field may be dependent on the type of sludge applied.

4. RUNOFF

4.1 Objectives

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

4.2 Materials and Methods

Field plots, 0.025 acres (0.01 hectare), with appropriate edging and runoff collection devices, were established for measuring runoff at the Elora Research Station on well to imperfectly drained silt loam soils. Iron-precipitated sludge from the North Toronto sewage treatment plant was applied to separate plots in November 1972 and January 1973.

The method of application and the manner in which the sludge was held by the snow are shown in Figures 1 and 2, respectively. A third application will be made in April. Rates of application are based on the nitrogen content of the sludge and will supply 178 lb N/acre (200 kg N/ha) and 714 lb N/acre (800 kg N/ha) on a 2% slope; and 178 lb N/acre (200 kg N/ha) on a 6% slope (treatments without sludge are provided on each slope). Two replications of each treatment are provided.

After each runoff event, the volumes are measured, samples are taken, and tanks are emptied. The samples will be composited into one sample per plot for each application period. Each plot will be harvested in the fall and the stover will be left on the surface for return to the soil.

4.3 Results and Discussion

Treatments were commenced with applications in November 1972 and January 1973. During the period, to the date of this report, (March 27, 1973) eight runoff events occurred - four in January, one in February, and three in March. The cumulative runoff volumes for January and February, together with the nitrogen, phosphorus and potassium applied and lost are given in Tables 1 to 3. Values are given for undigested and for digested samples to distinguish between water soluble

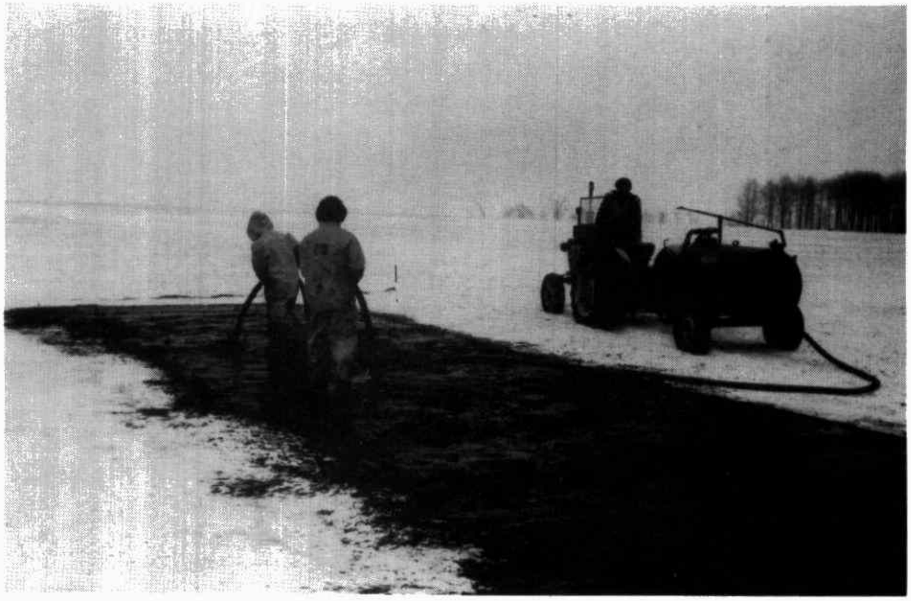

FIGURE 1. SLUDGE APPLICATION.

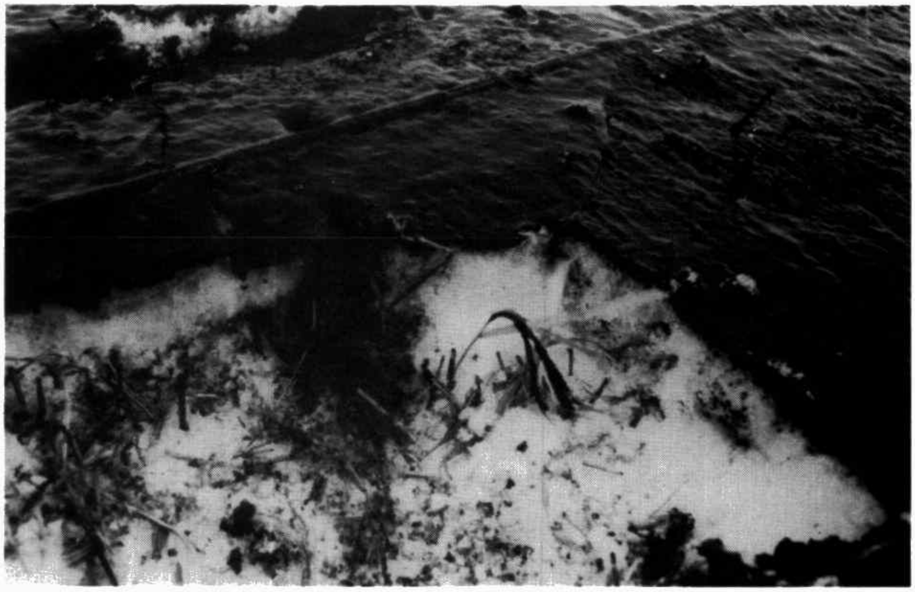

FIGURE 2. SLUDGE COVER FROM WINTER APPLICATION.

TABLE 1. Nitrogen Added in Iron-Treated Sewage Sludge and Lost from 2% and 6% Slopes from December 1972 to February 1973.

Precipitation for the period 6.3 in (16.2 cm)
Maximum snow depth 5 in (12.7 cm)

Treatment	N applied lb/acre (kg/ha)	N loss		% N loss		run-off in (cm)
		total lb/acre (kg/ha)	soluble lb/acre (kg/ha)	total	soluble	
		6% slope				
Fall*	62 (69)	1.5 (1.6)	0.96 (1.1)	2.4	1.6	1.9 (4.9)
Winter	180 (200)	13.0 (14.0)	9.0 (10.0)	7.1	5.1	2.4 (6.0)
Check		0.40 (0.45)	0.14 (0.16)			1.2 (3.0)
		2% slope				
Fall*	62 (69)	1.2 (1.4)	0.50 (0.56)	2.0	0.80	2.5 (6.6)
Fall*	230 (260)	5.0 (5.7)	3.0 (3.7)	2.2	1.3	2.3 (5.7)
Winter	178 (200)	5.6 (6.3)	3.6 (4.1)	3.1	2.1	2.3 (5.7)
Winter	710 (800)	27.0 (31.0)	18.0 (19.0)	3.8	2.3	1.9 (4.8)
Check		0.99 (1.1)	0.59 (0.66)			2.4 (6.0)

* Fall 1972 applications were below scheduled amounts, balance will be made up in spring 1973.

TABLE 2 Phosphorus Added in Iron-Treated Sewage Sludge and Lost from 2% and 6% Slopes from December 1972 to February 1973.

Precipitation for the period 6.3 in (16.2 cm)
Maximum snow depth 5 in (12.7 cm)

Treatment lb N/acre (kg/ha)	P applied lb/acre (kg/ha)	P loss total lb/acre (kg/ha)	P loss soluble lb/acre (kg/ha)	% P loss total	% P loss soluble	run-off in (cm)
		6% slope				
Fall* 178 (200)	79 (88)	0.19 (0.21)	0.18 (0.20)	0.24	0.22	1.9 (4.9)
Winter 178 (200)	240 (270)	0.91 (1.0)	0.72 (0.81)	0.39	0.31	2.4 (6.0)
Check		0.06 (0.09)	0.06 (0.09)			1.2 (3.0)
		2% slope				
Fall* 178 (200)	80 (90)	0.16 (0.18)	0.10 (0.11)	0.20	0.13	2.5 (6.6)
Fall* 714 (800)	290 (330)	0.29 (0.32)	0.26 (0.29)	0.10	0.09	2.3 (5.7)
Winter 178 (200)	240 (270)	0.46 (0.52)	0.35 (0.39)	0.20	0.15	2.3 (5.7)
Winter 714 (800)	940 (1060)	0.97 (1.1)	0.69 (0.78)	0.10	0.07	1.9 (4.8)
Check		0.21 (0.24)	0.09 (0.10)			2.4 (6.0)

*Fall 1972 applications were below scheduled amounts, balance will be made up in spring 1973.

TABLE 3 Potassium Added in Iron-Treated Sewage Sludge and Lost from 2% and 6% Slopes from December 1972 to February 1973.

Precipitation for the period 6.3 in (16.2 cm)
Maximum snow depth 5 in (12.7 cm)

Treatment lb N/acre (kg N/ha)	K applied lb/acre (kg/ha)	K loss		run-off in (cm)
		total lb/acre (kg/ha)	soluble lb/acre (kg/ha)	
		6% slope		
Fall* 178 (200)	4.5 (5.0)	12.0 (13.0)	10.0 (12.0)	1.9 (4.9)
Winter 178 (200)	11.0 (12.0)	12.0) (13.0)	11.0) (12.0)	2.4 (6.0)
Check		11 (12.0)	10.0) (12.0)	1.2 (3.0)
		2% slope		
Fall* 178 (200)	4.5 (5.0)	6.7 (7.5)	5.0 (5.6)	2.5 (6.6)
Fall* 714 (800)	17.0 (19.0)	8.3 (9.3)	6.6 (7.4)	2.3 (5.7)
Winter 178 (200)	11.0 (12.0)	8.2 (9.2)	6.7 (7.5)	2.3 (5.7)
Winter 714 (800)	43.0 (48.0)	9.8 (11.0)	8.1 (9.1)	1.9 (4.8)
Check		9.2 (10.0)	8.0 (9.0)	2.4 (6.0)

* Fall 1972 applications were below scheduled amounts, balance will be made up in spring 1973.

and total fractions.

Heavy metal analyses (analyzed by Dr. Jon C. Van Loon, University of Toronto) of runoff on February 5th, 1973 from 2% slope are summarized in Table 4. The COD of water samples from runoff on March 5, 1973 were 140 mg/l and 64 mg/l for plots treated with 714 lb N/acre (800 kg N/ha) and 0 lb N/acre, respectively as sludge. The heavy metal and COD analyses are preliminary checks. Both determinations will be made on water from all future runoff events.

TABLE 4. Heavy Metal Content of Runoff Water From 2% Slope.

Rate of Sludge Application	Pb	Zn	Ni	Cu	Cd	Hg
			(ppb)			
0	<1	<1	<1	5	<0.2	~0.2
714 lb N/acre (800 kg N/ha)	6	4	13	11	<0.2	<0.2

Although approximately one-quarter of the precipitation was lost in runoff from these plots, generally less than five per cent of the applied nutrients was lost. Since this was Winter runoff, there was no measureable soil or solid sludge carried by the runoff water which helps to explain the low level of nutrients.

Larger percentage losses of nutrients occurred with the Winter application, and the largest quantitative loss occurred with the heavier rates of application. The most serious loss in terms of potential pollution problems appears to be the 27 lb N/acre (30 kg N/ha) from the 714 lb N/acre (800 kg N/ha) application. If all this material were carried to streams from a sufficiently large number of acres, water quality would be adversely affected. Fortunately, much of it would be held back by intervening land and the extent of this retention should be determined.

4.4 Conclusions

1. The procedures set up to determine rates of sewage sludge which may be safely applied appeared to be satisfactory.

2. From the first Winter results, there were indications that the iron-precipitated sludge decreased water infiltration, and that the runoff loss of nutrients (5 per cent of application) tended to be relatively less than the runoff loss of water (25 per cent of precipitation).

3. In this particular season with an abnormally high Winter precipitation in the form of rain, more runoff occurred from a Winter application than from a Fall application.

4. If 10 lb N/acre (11.2 kg N/ha) can be considered a safe loss (assuming that intervening land will absorb this amount prior to runoff reaching a stream) Fall and Winter sludge applications to 6% and 2% slopes must be kept below rates of 180 lb N/acre (200 kg N/ha) and 710 lb N/acre (800 kg N/ha), respectively.

5. Phosphorus and heavy metal losses from the sludge used in this study appeared to be insignificant.

The lower runoff from the non-sludge treated plot on the 6% slope must be verified before it can be considered real, although a tendency for sludge to prevent the passage of water into the soil has been noted. As is shown in Figures 1 and 2, the sludge application forms a complete film over the soil surface.

5. SOIL CHARACTERIZATION

5.1 Objectives

To describe the macromorphology, micromorphology, and chemical and physical states of the soils before sewage sludge is applied, characterization studies were undertaken. These studies may make it possible to predict the effect on the soils of sewage sludge application and may also explain seemingly anomalous results in other portions of the project.

5.2 Methods and Materials

Two soil profiles were sampled from the runoff plots. The profiles were described according to the "System of Soil Classification for Canada" (Canada Dept. of Agriculture, 1970). Particle size analyses were performed by sieving and the pipette method (Kilmer and Alexander, 1949), following the destruction of organic matter with H_2O_2 and dispersion by calgon (Tyner, 1939). Organic matter was determined by the wet oxidation method (Walkley, 1947). The pH determinations were done in 1:1 soil to water suspensions and in 0.01 m $CaCl_2$ (Jackson, 1958).

5.2.1 Sampling to Date

Two soil profiles from the Elora runoff experiments were sampled. Profile #1 will probably fit into the Conestoga soil series and profile #2 into the Colwood soil series. In total thirty-one subsamples have been collected from the two profiles for physical and chemical analysis. Fifteen 6" x 4" x 2" undisturbed samples have been collected for thin section preparation.

5.2.2 Analyses to Date

The macromorphology of each profile has been described (Appendix, Tables A1 and A2). Particle size distribution analysis has been completed for profile #1 (Appendix, Table A3) and partially completed for profile #2 (Appendix, Table A4). Organic matter content and pH values with depth have been determined (Appendix, Tables A5 and A6).

The nine undisturbed samples from profile #1 have been impregnated and are now hardening. The blocks must be dried to an air dry state at room temperature. After the impregnating medium (Vestapol & Styrene) has been added a one to two month setting and curing time is required (Altemuller, 1962).

Chemical and mineralogical analyses are still in progress.

5.3 Results and Discussion

Profile #1 was found to have a greater organic matter content with depth than profile #2. This may be cumulic matter. Both profiles are essentially neutral in reaction down to approximately 24 inches.

The influence of organic matter content and pH of these soils on sludge is not predictable at this time. However, if the organic matter is not cumulic then these soils do permit organic matter to move into the profiles. The answers to these questions will be obtained from petrographic observation of thin sections. The final horizonation of these profiles will depend on the extractable Fe content, which has not yet been determined.

From the macromorphological descriptions (Appendix, Tables A7 and A8 it is apparent that the runoff plots have many individual minor aquafers. This is best illustrated by the sharp increase to 32% of the gravel content at 21 inches in profile #2. This zone acts like a field tile in draining the soil.

The soils were observed in each of the runoff collection tank pits. From the initial field examination it is apparent that the subsurface drainage in the runoff plots will be controlled by sand and gravel layers which are located between the surface silt loam deposit and the underlying till. In the Fall of 1972 subsurface water flow was much greater in this coarser textured lens. The following conclusion may therefore be made: (1) The accurate sampling of groundwater will be very difficult; (2) bulk sampling of soils for determination of potential pollutants will have to be done with caution; (3) the location of preferential zones of water movement will be essential; (4) it will be very necessary to collect information on more than one soil type because of the unique characteristics of each soil location; and, (5) in situ measurements of heavy metal distribution (by micropedological methods) will eventually be necessary in order to determine their rate of movement and ultimate fate.

6. MICROBIAL EXAMINATION AND OBSERVATIONS

6.1 Objectives

The work done has been an attempt to establish the numbers and types of microorganisms present in three different sludges and the runoff waters from sludge treated plots.

6.2 Materials

After a number of trials, using samples of digester sludge, soil and water, general methods of handling and preparing dilutions were established.

The sludges and soils are being handled on a weight basis. Ten gram aliquots are being aseptically weighed for use in the general microbiological examination. In order to be able to express the results on a dry weight basis, if desired, similar 10 g aliquots have been prepared and dried at 105° for 24 hours. It is probably questionable how much importance should be attached to this procedure, particularly in the case of some sludges. The results will be expressed in this report on the basis of the sample as taken, not on the dry weight equivalent.

The runoff water is being handled by volume measurement in the usual manner.

Fifty gram or 50 ml samples are being used as inocula in the enrichment media to detect the presence of salmonella.

After trial runs using a variety of media, a system of microbiological examination was established. Lactose broth, Brilliant Green Bile Lactose broth, and EC broth were used in multiple tube dilation series to determine the most probable number of total coliforms and faecal coliforms. Similarly, faecal streptococci were estimated using KF Streptococcus broth.

Pour plates of the dilutions were prepared using Pseudomonas Isolation Agar, Neopeptone Dextrose Rose Bengal Agar (fungi) and Tryptone Glucose Extract Agar containing brilliant green. The last one is intended to permit an estimation of non-spore forming organisms. The almost constant presence of spreading spore-forming types made the use of such a selective medium necessary. The number of spore-forming types was estimated by using a pasteurization process followed by culturing on Tryptone Glucose Extract Agar.

Tetrathionate and Selenite Brilliant Green broths were used to detect salmonella. Plates of MacConkey Agar, Brilliant Green Sulfa Agar and Hektoen Agar were streak inoculated from such selective enrichment cultures.

Examination of samples has been restricted to the runoff water from the Elora plots. Examination of soil-sludge samples from the greenhouse experiment will begin shortly.

For details concerning the runoff plots, sample collection, climatic conditions and other pertinent information the reader is referred to Section 4.

6.3 Discussion

Some microbiological characteristics of the three chemically treated digested sewage sludges are presented in Table 5. Two of these sludges may contain salmonella. Salmonella were not detected in the Newmarket sludge.

Some microbiological characteristics of the runoff water collected January 3 are presented in Table 6. The coliform, faecal coliform and faecal streptococci are expressed here as less than 23/100 ml because of dilutions arbitrarily selected. Why the sample from plot 22 should contain such a relatively high concentration of faecal streptococci is not apparent. There was no evidence of salmonella in the 50 ml aliquots of these runoff samples.

The microbiological characteristics of the runoff water collected January 23 are presented in Table 7. The 'zero' indication in Table 7 for the faecal coliforms and faecal streptococci indicates a relatively small number of such organisms compared to the total coliforms. It was difficult to select satisfactory dilutions for the enumeration of these three groups of indicator bacteria. Salmonella may be present in the water from some plots. These isolates, from plots 8, 12, 14 and 15, have appeared on the selective - differential plating media as possible salmonella types and some of these have reacted to the

TABLE 5. Some Microbiological Characteristics of the Three Sludges.

Organisms or Media	North Toronto (Iron)	Point Edward (Alum)	Newmarket (Lime)
Total Coliforms*	790,000/100 ml	1,300,000/100 ml	2,220,000/100 ml
Faecal Coliforms*	120,000/100 ml	330,000/100 ml	280,000/100 ml
Faecal Streptococci*	70,000/100 ml	17,000/100 ml	790,000/100 ml
Pseudomonas Isolation Agar	1,000/ml	82,000/ml	13,800/ml
T.G.E. Agar- Pasteurized**	94,000/ml	17,000/ml	5,500/ml
T.G.E. Agar- Br. Green	66,000/ml	1,760/ml	1,900/ml
NDR Agar	640/ml	370/ml	200/ml
Isolates Agglutinated***	Yes (2 of 6)	Yes (3 of 6)	No (0 of 12)

* MPN Procedure

** Sample pasteurized

*** Purified isolates tested with polyvalent O Salmonella antiserum.

TABLE 6. Some Microbiological Characteristics of Runoff Water. (January 3, 1973)

Organisms or Media	Plots									
	1	3	6	8	10	12	14	16	19	22
	W-178* (200)	F-178 (200)	CHECK	F-178 (200)	CHECK	F-178 (200)	F-714 (800)	F-178 (200)	W-178 (200)	F-178 (200)
Total Coliforms**	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23
Faecal Coliforms**	<23	<23	<23	<23	<23	<23	<23	<23	<23	<23
Faecal Streptococci**	<23	<23	<23	<23	<23	<23	<23	<23	<23	5400
Pseudomonas Isolation Agar	0/ml	0/ml	0/ml	0/ml	0/ml	4/ml	0/ml	0/ml	5/ml	290/ml
T.G.E. Agar Pasteurized***	100/ml	16/ml	180/ml	4/ml	12/ml	6/ml	10/ml	8/ml	25/ml	7/ml
T.G.E. Agar Br. Green	0/ml	3/ml	0/ml	0/ml	>30,000/ml	140/ml	>30,000/ml	>300/ml	>30,000/ml	>30,000/ml
NDR Agar	10/ml	19/ml	9/ml	1/ml	0/ml	3/ml	0/ml	4/ml	0	0
Possible Salmonella Isolates	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE

* Plot treatments expressed as lb N/acre (kg/ha).

** MPN Procedure. Number per 100 ml.

*** Sample pasteurized.

TABLE 7. Some Microbiological Characteristics of Runoff Waters. (January 23, 1973)

Organisms or Media	Plots						
	1	3	6	7	8	9	10
	W-178 (200)	F-178 (200)	CHECK	W-178 (200)	F-178 (200)	W-178 (200)	CHECK
Total Coliforms*	1,600,000	2,300	4,500	110,000	3,000	240,000	90,000
Faecal Coliforms*	7,400	0	0	2,000	0	0	0
Faecal Streptococci*	0	0	0	0	110	0	78
Pseudomonas Isolation Agar	370,000/ml	2,400/ml	220/ml	20,000/ml	0/ml	400/ml	6,500/ml
TGE Agar Pasteurized**	1,100/ml	100/ml	920/ml	400/ml	6,800/ml	70/ml	120/ml
TGE Agar Br. Green	9,200,000/ml	70,000/ml	5,000/ml	1,200,000/ml	16,000/ml	65,000/ml	370,000/ml
NDR Agar	6/ml	50/ml	60/ml	50/ml	20/ml	10/ml	15/ml
Possible Salmonella Isolates	NONE	NONE	NONE	YES	YES	NONE	NONE
Isolates Agglutinated***	---	---	---	NO	Yes (2 of 3)	---	---

---

* MPN Procedure. Number per 100 ml.

** Sample Pasteurized.

*** Purified isolates tested with polyvalent O Salmonella antiserum.

TABLE 7 (Cont'd)

Organisms or Media	Plots						
	12	14	15	16	19	20	22
	F-178	F-714	W-714	F-178	W-178	W-714	F-714
	(200)	(800)	(800)	(200)	(200)	(800)	(800)
Total Coliforms*	6,800	170,000	16,000	0	13,000	9,200,000	49,000
Faecal Coliforms*	0	0	130	0	0	0	0
Faecal Streptococci*	0	0	79,000	0	68	4,300	490
Pseudomonas Isolation Agar	400/ml	86,000/ml	138,000/ml	0	170/ml	2,000/ml	1,400/ml
TGE Agar Pasteurized**	460/ml	240/ml	1,900/ml	400/ml	880/ml	150/ml	120/ml
TGE Agar Br. Green	84,000/ml	2,700,000/ml	1,400,000/ml	185,000/ml	150,000/ml	1,200,000/ml	0/ml
NDR Agar	220/ml	80/ml	40/ml	140/ml	9/ml	280,000/ml	75/ml
Possible Salmonella Isolates	YES	YES	YES	NONE	NONE	NONE	NONE
Isolates Agglutinated***	YES (3 of 3)	YES (2 of 2)	YES (1 of 1)	---	---	---	---

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* MPN Procedure. Number per 100 ml.

** Sample pasteurized.

*** Purified isolates tested with polyvalent O Salmonella antiserum polyvalent 0 salmonella antiserum. A more detailed examination of these isolates will be done. Of the plots concerned, two have received sludge at the rate of 178 lb N per acre (200 kg/ha) and two at the rate of 714 lb N per acre (800 kg/ha). Possible salmonella were not detected in the remaining six plots receiving 178 lb N per acre.

In general, the numbers of bacteria of the various groups detected in the sludge are much greater than the numbers found in the runoff samples. Exceptions occur with Tryptone Glucose Extract Brilliant Green Agar and Pseudomonas Isolation Agar. The opportunity for large numbers of indicator organisms to be present in the runoff water is evident.

The relatively small number of organisms in the runoff water of January 3 (Table 6) is associated with the frozen and snow covered surface conditions at that time. The Winter application of sludge was made on January 16 on top of several inches of snow cover. The very mild weather of January 19 for several days caused a thawing of the snow and sludge, and an abundant runoff. In this case the sludge was an intimate part of the runoff water. The organisms in the runoff water of January 3 (Table 6) were probably not associated with the sludge applied in the Fall but rather with the snow cover existing at the time.

The difference in concentration of many types of microorganisms in the two runoff collection can therefore probably be attributed to the physical relationship of the sludge, snow and rain during the January thaw. The Fall application of sludge was protected; the Winter application was in a position and condition to easily become part of the runoff water. The greatest number of coliforms, faecal coliforms, colonies on Pseudomonas Isolation Agar, and colonies on tryptone Glucose Extract Brilliant Green Agar were all associated with the Winter application of sludge and tend to be associated with high application rates.

6.4 Conclusions

The Fall application of sludge is associated with a reduced contribution of microorganisms to the runoff water.

The Winter application of sludge is associated with a marked contribution of microorganisms to the runoff water. The quality of waters receiving this runoff could be adversely affected.

The marked difference between the number of the various groups of microorganisms detected in the runoff water of January 3 and those detected in the runoff water of January 23 can, in part, be associated with the environmental conditions existing at the time of runoff water collection.

The relationship between the fate of the organisms, time of application, amount of sludge applied, and the physical state of the environment is subject to many variables. Consequently, predictions as to what will happen under particular circumstances must remain at this point highly speculative.

7. GREENHOUSE STUDIES

7.1 Objectives

1. To determine the effect of the three chemically treated sludges on plant growth and on nutrient and heavy metal uptake.
2. To find suitable extractants to measure plant available metals in soils.

7.2 Methods

The experiment involves two replications of sixty treatments which consist of all combinations of the factors listed below.

Treatments

Soils - Grimsby sandy loam
- Haldimand clay loam

Soil pH levels - adjusted before adding sludge
5.5
6.5
7.5

Sludges - lime treated (Newmarket)
- alum treated (Point Edward)
- ferric chloride treated (North Toronto)

Sludge rates - 0 (commercial fertilizer added)
178 lb N/acre (200 kg N/ha)
714 lb N/acre (800 kg N/ha)
4460 lb N/acre (5000 kg/ha)

Tests were run to determine the amount of lime required to bring each soil to the desired pH and the appropriate amount of lime was added to portions of each soil. Field capacity and wilting point were determined on each soil with each sludge treatment, after sludge application, and pots are watered by weight to avoid leaching and poor aeration. Trent barley was seeded February 19, the seed being treated with "vitaflow" systemic fungicide.

It is intended that a broad leaved crop (probably lettuce) will be grown after the barley. Following this second crop the two lower rates of sludge will be re-applied and further crops grown.

7.3 Discussion

Soil pH values will be measured periodically during the trial as they are expected to change as the experiment progresses. The pH values, measured one week after the trial was seeded, are presented in Table 8. All three sludges increased soil pH, the lime sludge having a quite marked effect as expected. The pH values are expected to drop somewhat as nitrogen in organic and ammonium form is converted to nitrate but only on those soils currently with pH values below 7.0. Those samples with pH values above 7.0 probably contain sufficient $CaCO_3$ to prevent the pH from dropping for some time.

Amounts of various nutrients and heavy metals applied with one rate of sludge (714 lb N/acre, 800 kg/ha) are presented in Table 9.

The number of plants emerged in each pot was recorded one week after seeding. At the 4460 lb/acre (5000 kg/ha) rate the lime and alum sludges delayed emergence and reduced the number of plants emerging (Table 10). This may be due to ammonia toxicity or to concentrations of other toxic materials. A few pots in these treatments produced such a small number of plants that they had to be re-seeded. Growth was slower with the highest rate of all sludges on both soils. With the iron sludge on the sandy loam soil plants which did emerge turned white and began to deteriorate at approximately 24 days after seeding. Growth differences and the chlorotic plants with iron and alum sludge are shown in Figure 3. The lime sludge treated plants are not shown in Figure 3 but appeared similar to the alum treated.

7.4 Conclusions

The 4450 lb N/acre (5000 kg/ha) rate of sludge is excessive for good crop growth at the initial stages. Further cropping and chemical analyses are required before other conclusions can be reached.

TABLE 8. Effect of Sewage Sludge on pH of Soils Limed to three Different pH Values Before Sludge Addition (values measured one week after seeding.

Nitrogen Applied in Sludge		Alum Sludge			Iron Sludge			Lime Sludge		
lb/ac	(kg/ha)	pH values								
					Haldimand Clay Loam					
0	(0)				4.7	5.9	7.5			
178	(200)	5.4	7.0	7.8	5.4	5.7	7.5	6.7	7.1	7.8
714	(800)	5.5	6.5	7.7	5.5	6.2	8.0	8.0	8.1	8.2
4455	(5000)	6.6	7.0	7.5	6.2	7.1	7.7	7.8	8.1	8.1
					Grimsby Sandy Loam					
0	(0)				4.7	6.2	7.3			
178	(200)	5.3	6.8	7.4	5.3	6.7	7.5	7.2	7.5	7.8
714	(800)	5.7	6.7	7.4	5.7	6.9	7.4	8.0	7.9	8.1
4460	(5000)	7.2	7.1	7.6	6.4	6.9	7.3	8.1	7.9	7.9

TABLE 9. Amounts of Various Nutrients and Heavy Metals in Sewage Sludges Applied in the Greenhouse at the Rate of 714 lb N per acre (800 kg/ha).

Nutrients or Heavy Metals	Alum Sludge lb/ac	Alum Sludge (kg/ha)	Iron Sludge lb/ac	Iron Sludge (kg/ha)	Lime Sludge lb/ac	Lime Sludge (kg/ha)
N	710	(800)	710	(800)	710	(800)
P	710	(800)	920	(1030)	590	(670)
K	80	(90)	50	(60)	70	(80)
Ca	460	(520)	740	(830)	15450	(17340)
Mg	210	(240)	100	(110)	360	(400)
Mn*	2.40	(2.70)	8.10	(9.10)	17.7	(19.8)
Zn*	23.3	(26.1)	55.4	(62.1)	37.6	(42.2)
Cu*	16.4	(18.4)	20.3	(22.8)	12.8	(14.3)
B	0.80	(0.90)	0.50	(0.60)	3.60	(4.00)
Cd*	0.20	(0.20)	0.30	(0.30)	0.20	(0.20)
Cr*	1.90	(2.20)	14.4	(16.2)	1.50	(1.70)
Pb*	10.7	(12.0)	18.1	(20.3)	10.5	(11.8)
Ni*	1.20	(1.30)	0.60	(0.70)	0.20	(0.20)

* Analyses provided by Dr. J. Van Loon, Dept. of Geology, University of Toronto.

TABLE 10. Emergence Counts taken Seven Days after Seeding

Nitrogen in sludge lb/ac	Applied (kg/ha)	Alum Sludge			Iron Sludge			Lime Sludge		
		approx. soil pH before adding sludge								
		5.5	6.5	7.5	5.5	6.5	7.5	5.5	6.5	7.5
		emergence - plants/pots								
0	(0)	11.5	11.5	12.0	11.5	11.5	12.0	11.5	11.5	12.0
178	(200)	10.0	11.0	11.0	11.0	11.0	10.0	11.0	10.0	10.0
713	(800)	11.5	11.0	10.0	11.0	11.0	11.0	11.0	11.0	11.0
4455	(5000)	11.0	12.0	11.5	6.0	9.0	8.0	1.0	1.5	4.0

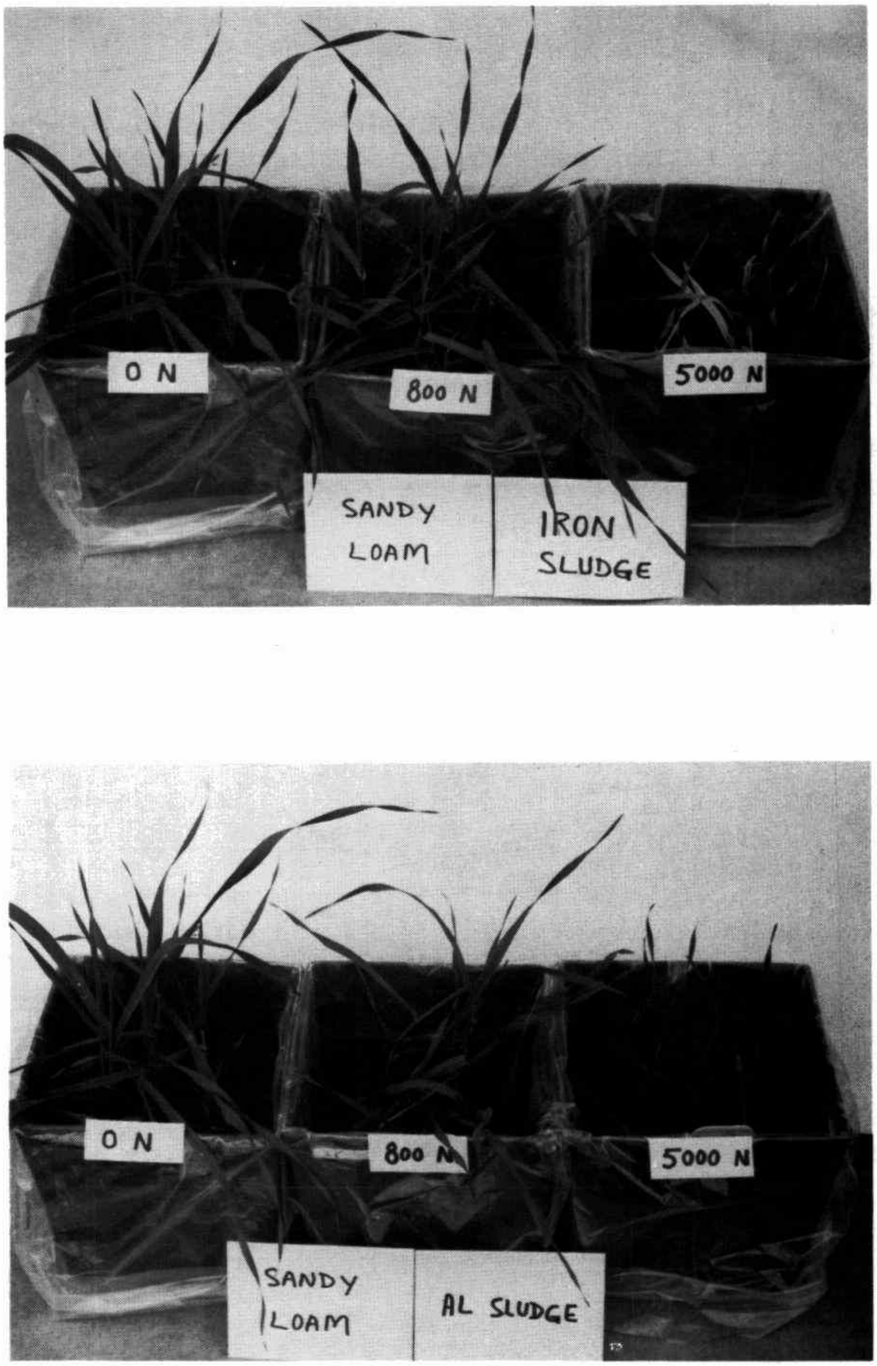

FIGURE 3. TRENT BARLEY SEEDLINGS AT 24 DAYS OF AGE ON GRIMSBY SANDY LOAM WITH RATES OF SLUDGE SUPPLYING 0, 714, AND 4455 lb N/acre (0, 800, and 5,000 kg/ha).

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APPENDIX

SOIL PROFILE DESCRIPTIONS

APPENDIX

TABLE A1. Description of Profile # 1 from the Runoff Plots.

Location - Elora Farm, Sludge Runoff Plots.
On north side of Tank Number 3.

Parent Material - Silt loam alluvium over till

Landform - Side slope on a till plain

Slope - 5%

Order - Brunisolic

Great Group - Melanic Brunisol

Subgroup - Gleyed Orthic Melanic Brunisol

Family - Medium, mixed, moderately to very strongly calcareous

Series - Conestoga Silt Loam

Horizon	Depth	Descriptions
	inches (cm)	
Ah	0 - 8 (0 - 20.5)	Very dark grayish brown (10YR3/2, m), grayish brown (10YR5/2, d) silt loam, coarse subangular blocky breaking to medium and fine granular, friable (m). hard (d), many fine and very fine tubules, abundant roots, gradual boundary;
Ae	8 - 15 (20.5 - 38.0)	Yellowish brown (10Yr5/6, m) upper 10 cm have 10% very dark grayish brown (10YR3/2, m) earthworn casts the lower 7.5 cm have a few faint Mn stains, silt loam, coarse subangular blocky breaking to medium and fine granular, friable (m), hard (d), few worm casts, many fine and very fine tubules, few roots, gradual boundary;
Aeg	15 - 21 (38.0 - 53.5)	Mixed colours, yellowish brown (10YR5/4, m) with 50% brownish yellow (10YR6/8, m) mottles, many fine Mn stains (7.5YR3/2, m), light yellowish brown (10YR6/4, d) and 50% yellow (10YR7/6, d) silt loam, coarse subangular blocky, breaking to fine granular, friable (m), hard (d), many fine and very fine tubules, few worm casts, few fine roots, gradual boundary;

TABLE Al cont.

Btjg	21 - 24 (53.5- 61.0)	Mixed colours, brownish yellow (10YR6/6, m) light olive brown (2.5Y5/6, m) light brownish grey (10YR6/2,m) and dark brown (7.5YR3/2, m) dominant colour is light yellowish brown (10YR6/4, m) silt loam, coarse subangular blocky breaking to fine subangular blocky and fine granular, friable (m), slightly hard (d), many fine and very fine tubules, few fine roots, abrupt boundary;
llBtjg	24 - 27 (61.0 - 68.5)	Same as above except contains more gravel.
lllBtjg	27 - 30 (68.5 - 76.0)	Mixed colours dark brown (10YR4/3, m) and light yellowish brown (2.5Y6/4, m) very pale brown (10YR7/4, d) medium sandy loam, massive, friable (m), slightly hard (d), many fine and very fine tubules, few fine roots, abrupt boundary;
lVCkg	30 - 52 (76.0 - 132)	Light yellowish brown (10YR6/4, m), very pale brown (10YR7/3, d) massive, loam, friable (m), hard (d), many fine and very fine tubules, few fine roots.

TABLE A2. Description of Profile # 2 from the Runoff Plots.

Location - Elora Farm, sludge runoff plots. North side of tank number 13.

Parent Material - Silt Loam alluvium over till

Landform - Toe slope on a till plain

Slope - 2%

Order - Gleysolic

Great Group - Humic Gleysol

Subgroup - Orthic Humic Gleysol

Family - Medium, mixed, acid to neutral, moderately to very strongly calcareous

Series - Colwood Silt Loam

Horizon	Depth	Description
	inches (cm)	
Ah	0 - 9 (0 -23)	Very dark greyish brown (10YR3/2, m) grayish brown (10YR5/2, d), silt loam, coarse subangular blocky breaking to fine subangular blocky and medium granular, friable (m), slightly hard (d), many fine and very fine tubules, abundant tubules, abrupt boundary;
Ahe	9 -12 (23 - 30.5)	Mixed colours brown and very dark greyish brown (10YR4/2 and 10YR3/3, m), yellow and pale brown (10R7/6 and 10YR6/3, d), silt loam, coarse blocky breaking to fine granular, friable (m), soft (d), many fine and very fine tubules, many earthworm casts, plentiful fine roots, gradual boundary;
Btj	12 - 14 (30.5 -35.5)	Brown (10YR5.5/4.5, m) light brown (10YR6.5/5, d), silt loam, medium subangular locky breaking to fine granular, friable (m), slightly hard (d), many fine and very fine tubules, plentiful fine roots, grandual boundary;
Btjg	14 - 16	(10YR5/6 and 10YR7/6, m) few fine Mn stains (7.5YR3/2,m). Light brown (10R6/4, d), silt loam medium subangular blocky breaking to fine granular, friable (m), hard (d), many fine and very fine tubules, few fine roots, gradual boundary;

TABLE A2. cont.

11Bcg1	16 - 18 (40.5 - 46.0)	Mixed colours strong brown and reddish yellow (10YR5/6 and 10YR736, m) few fine Mn stains (7.5YR3/2, m) pink (10YR7/4, d) coarse sandy loam, medium subangular blocky breaking to fine granular and single grain, friable (m), slightly hard (d), many fine and very fine tubules, few fine roots, abrupt boundary;
11BCg2	18 - 19.5 (46.0 - 49.5)	Brown (10YR5/4, m) with few fine Mn stains (7.5YR3/2, m) pink (10YR7/4, d) coarse sandy loam, coarse blocky breaking to fine granular, friable (m), hard (d), many fine and very fine tubules, few fine roots, gradual boundary;
111Ckg	19.5 - 25 (49.5 - 63.5)	Brown (10YR5/4, m) with few fine Mn stains (7.5 YR3/2, m) pink (10YR7/4, d) loam massive friable (m), very hard (d), many fine and very fine tubules, few fine roots, abrupt boundary; Note: (wood charcoal chip -rom 19.5 - 22 inches subsample, in thin section sample the 22 -25 inches subsample appears different).
1Vckg	25 - 36 (63.5 - 81.5)	Mixed colours brown and pinkish gray (10YR5/4 and 10YR6/2, m), pink and pinkish white (10YR8/4 and 8/2, d) loam, coarse subangular blocky breaking to fine granular, friable (m), hard (d), many fine and very fine tubules, few fine roots, water table at 33 inches.

TABLE A3. Particle Size Distribution of Profile #1

Horizon	Depth Inches (Cm)	% of <2000μ fraction								% of Total Soi
		<2	2-20	20-50	50-100	100-250	250-500	500-1000	1000-2000	>2000μ
Ah	0-3 (0-7.5)	23.1	1.4	18.0	32.4	15.7	4.6	2.7	2.2	1.0
	3-6 (7.5-15.0)	28.7	7.4	1.6	36.1	18.7	5.5	3.9	1.4	0.9
	6-8 (15.0-20.5)	21.2	21.7	21.2	18.5	10.2	3.3	1.9	2.1	0.9
Ae	8-12 (20.5-30.5)	24.1	26.7	7.7	32.2	5.1	1.7	1.4	1.2	0.4
	12-15 (30.5-38.0)	16.6	29.2	25.8	21.7	4.1	1.0	0.9	0.8	0.3
Aeg	15-18 (38.0-45.5)	19.6	24.3	18.6	30.9	3.9	1.2	0.9	0.6	0.1
	18-21 (45.5-53.0)	15.5	23.0	19.2	31.0	7.8	2.0	1.1	0.3	0.4
Btjg	21-24 (53.0-61.0)	11.9	23.8	11.9	33.0	16.7	1.0	1.3	0.3	3.2
IIBtjg	24-27 (61.0-68.5)	8.1	11.9	11.9	31.5	24.5	7.6	3.1	1.5	7.4
IIIBtjg	27-30 (68.5-76.0)	4.7	9.3	3.7	24.2	35.9	13.6	5.0	3.5	3.8
IVCkg	30-33 (76.0-83.5)	8.2	11.8	15.9	24.6	23.3	6.6	4.5	4.9	17.7
	33-36 (83.5-91.0)	11.1	13.3	16.7	24.4	21.8	5.0	4.7	3.0	12.0
	36-39 (91.0-99.0)	10.3	21.7	8.1	22.8	20.0	5.4	4.8	7.4	21.7
	39-42 (99.0-106.0)	14.0	10.0	3.3	29.0	26.8	7.1	5.0	4.9	13.2

TABLE A3. Cont.

Horizon	Depth Inches (Cm)	% of <2000µ fraction								% of Total Soil
		<2	2-20	20-50	50-100	100-250	250-500	500-1000	1000-2000	>2000µ
IVCkg	42-45 (106.0-113.5)	---	---	---	---	---	---	---	---	25.1
	45-48 (113.5-122.0)	---	---	---	---	---	---	---	---	23.1
	48-52 (122.0-132.0)	---	---	---	---	---	---	---	---	29.6

TABLE A4. Particle Size Distribution of Profile #2.

Horizon	Depth Inches (Cm)	% of <2000μ fraction								% of Total Soil
		<2	2-20	20-50	50-100	100-250	250-500	500-1000	1000-2000	>2000μ
Ah	0-3 (0-7.5)	27.4	4.0	3.2	29.6	21.2	8.1	3.5	3.0	2.0
	3-6 (7.5-.5.0)	28.6	0.0	2.6	32.0	21.8	8.2	5.0	1.8	0.9
	6-9 (15.0-23.0)	13.1	13.9	10.8	32.1	24.4	9.9	12.1	5.3	0.6
Ahe	9-12 (23.0-30.5)	19.4	13.8	6.3	23.1	19.4	8.2	11.1	11.3	1.8
Btj	12-14 (30.5-35.5)	27.5	14.4	0.7	24.7	19.3	7.7	4.3	1.5	2.1
Btjg	14-16 (35.5-40.5)	13.7	11.8	10.3	26.7	23.4	9.6	3.3	1.2	5.8
IIBcg1	16-18 (40.5-45.5)	7.8	3.0	6.0	29.7	35.2	11.8	5.1	1.6	2.9
BCg2	18-19.5 (45.5-48.5)	5.9	6.9	0.0	27.6	40.8	13.0	4.7	1.0	12.5
IIICKg	19.5-22 (48.5-56.0)	3.9	2.9	5.4	32.1	35.2	10.0	6.3	4.2	31.8
	22-25 (56.0-63.5)	8.6	7.7	7.3	22.6	38.9	6.9	5.8	2.3	16.2
IVCkg	25-28 (63.5-71.0)	13.1	6.9	2.1	31.0	32.1	8.0	4.2	2.7	9.0
	28-31 (71.0-78.5)	12.3	16.9	11.0	28.7	15.0	6.2	5.0	4.8	9.9
	31-34 (78.5-86.5)	14.3	7.5	10.6	28.4	27.5	5.4	4.3	2.1	1.7
	34-36 (86.5-91.5)	8.8	3.5	9.3	31.8	24.0	5.5	4.2	12.8	11.7

TABLE A5. Organic matter and pH Distribution of Profile #1.

Horizon	Depth		Organic Matter	pH	
	Inches	(Cm)	%	H_2O	$CaCl_2$
Ah	0-3	(0-7.5)	3.9	7.3	6.7
	3-6	(7.5-15.0)	3.5	7.3	6.7
	6-8	(15.0-20.5)	3.2	7.3	6.8
Ae	8-12	(20.5-30.5)	1.1	7.2	---
	12-15	(30.5-38.0)	0.8	7.3	6.7
Aeg	15-18	(38.0-45.5)	0.5	7.4	6.5
	18-21	(45.5-53.0)	0.5	7.5	6.7
Btjg	21-24	(53.0-61.0)	0.7	7.3	6.5
IIBtjg	24-27	(61.0-68.5)	0.8	7.3	6.6
IIIBtjg	27-30	(68.5-76.0)	0.9	7.6	6.7
IVCkg	30-33	(76.0-83.5)	0.7	8.0	6.9
	33-36	(83.5-81.0)	0.4	8.1	6.9
	36-39	(91.0-99.0)	0.5	8.1	6.9
	39-42	(99.0-106.0)	0.6	8.2	7.0
	42-45	(106.0-113.5)	0.5	7.9	6.9
	45-48	(113.5-122.0)	0.6	8.1	7.0
	48-52	(122.0-132.0)	---	8.1	7.0

TABLE A6. Organic Matter and pH Distribution of Profile #2

Horizon	Depth		Organic Matter	pH	
	Inches	(Cm)	%	H_2O	$CaCl_2$
Ah	0-3	(0-7.5)	4.4	7.1	6.7
	3-6	(7.5-15.0)	3.5	7.4	6.7
	6-9	(15.0-23.0)	4.1	7.2	6.6
Ahe	9-12	(23.0-30.5)	3.2	7.2	6.6
Btj	12-14	(30.5-35.5)	1.3	7.2	6.6
Btjg	14-16	(35.5-40.5)	1.3	7.3	6.6
IIBCg1	16-18	(40.5-45.5)	0.5	7.6	6.5
BCg2	18-19.5	(45.5-48.5)	0.0	7.5	6.4
IIICkg	19.5-22	(48.5-56.0)	0.4	7.7	6.5
	22-25	(56.0-63.5)	0.0	7.5	6.6
IVCkg	25-28	(63.5-71.0)	0.0	7.5	7.0
	28-31	(71.0-78.5)	0.0	7.6	6.9
	31-34	(78.5-86.5)	0.1	7.5	6.9
	34-36	(86.5-91.5)	0.2	7.6	6.9

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